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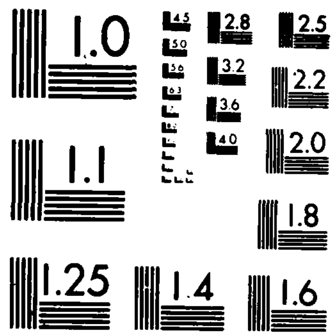

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EXPERIMENTAL STUDY TO DETERMINE A TECHNIQUE FOR LOADING REPRODUCIBLE MUD LAYERS ON URETHANE-PAINTED METAL SURFACES

by Juan D. Lopez
RESEARCH DIRECTORATE

February 1987

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This study established a procedure for loading reproducible mud layers on urethane-painted metal surfaces for use in laboratory decontamination studies. A technique was also developed to increase the thickness of the layer of mud by repeatedly dipping the metal surface in the mud solution after the previous layer had dried. The optimum temperature to accelerate the drying time was also determined. The results show that the optimum mud-loading procedure involves dipping test plates in a mud mixture (5 parts montmorillonite clay, 1 part silica sand, and 60 parts water) and drying in an oven at 50 °C for 1 hr after each mud layer is applied. (Keywords

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PREFACE

The work described in this report was authorized under Project 1L162706A553F, CB Decontamination and Contamination Avoidance. This work was started in July 1983 and completed in August 1983. Experimental data are contained in laboratory notebook 83-0122.

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EXPERIMENTAL STUDY TO DETERMINE A TECHNIQUE FOR LOADING REPRODUCIBLE MUD LAYERS ON URETHANE-PAINTED METAL SURFACES

1. INTRODUCTION

Vehicles and equipment used on the battlefield frequently become mud covered. In the event of chemical agent attack, the presence of mud can strongly affect the performance of decontamination operations. Consequently, mud covered surfaces must be considered to correctly assess the performance of decontamination techniques as well as to conduct threat modeling studies.

The experimental investigation described in this report evaluates the factors involved with applying a mud coating on polyurethane-painted metal surfaces and presents a method for reproducibly applying such a coating. Using this technique, controlled laboratory studies can be conducted to better define the influence of mud-coated surfaces on decontamination processes.

Several mud compositions were evaluated to identify one that would adhere to the test surface and provide reproducible loading by weight and thickness. Different soil-to-water ratios, loading procedures, and drying conditions were considered.

2. EXPERIMENTAL PROCEDURE AND RESULTS

2.1 Mud Composition and Loading Techniques.

2.1.1 Purpose.

This phase of the study was to establish a qualitative comparison of two mud mixtures in order to select the one that offered the best surface retention and provided the most uniform layer thickness. Two mud-loading techniques were also compared.

The factors evaluated were surface adhesion, concentration gradient across the test surface, variation in layer thickness, mud viscosity, evaporation rate, and effect of water concentration in the mixture. These criteria are further described in Table 1.

Table 1. Criteria for Variables Affected by the Water Content and Loading Procedures of the Mud Mixtures

Load Surface	Variable	Evaluation Criteria
Wet Mud	Viscosity	Relative difficulty to flow from stock bottle to test surface.
	Surface Adhesion	Relative retention on test surface when holding the plate in a vertical position.
	Evaporation Time	Comparison of time required for mud to dry on the test surface.
Dry Mud	Surface Adhesion	Relative ease of detachment when scratching test surface with a spatula.
	Concentration Gradient	Visual observation of any difference in solids concentration from the center to the edge of the test surface.
	Layer Uniformity	Visual comparison of uniformity of distribution and smoothness of the layer formed.

2.1.2 Experimental Procedure.

The two mud mixtures were Arizona road dust* and a blend of montmorillonite clay and silica sand.** Mud samples were prepared by adding various proportions of water to 3 g of the Arizona road dust or to a blend of 2.5 g clay and 0.5 g sand. A random test matrix (Table 2), which was used to prepare the mixtures and to establish the test sequence, identifies the specific test conditions evaluated.

Steel disks, 1.5 inches in diameter (3.81 cm), painted on one side with polyurethane paint (dust and grease free), were used as the test surfaces. Using the first loading method, we placed a droplet of mud mixture (approximately 1 ml) on the painted surface. Using the second method, we dipped the painted surface in the mud mixture for 10 sec and then drained the excess mud off by revolving the disk in a vertical position for 10 sec. A magnet was applied to the unpainted surface to control the loading process and prevent mud contamination of the unpainted surface.

The viscosity of the wet mud, initial adhesion of the mud to the test surface, and evaporation time were determined for each test condition. After drying the mud-coated test plate at ambient conditions (32 °C), final adhesion of the mud layer was observed by scratching with a spatula. The uniformity of the deposited layer and the presence of concentration gradients were also compared. All test plates were observed at similar ambient conditions and drying times.

To assist in the comparison, a relative scoring scheme of one to five points was used; the lowest score represented the most desired performance.

2.1.3 Results.

Figures 1 and 2 are samples of the test surfaces after the mud dried and was analyzed. The results of the analysis and scoring for each mixture are given in Table 3.

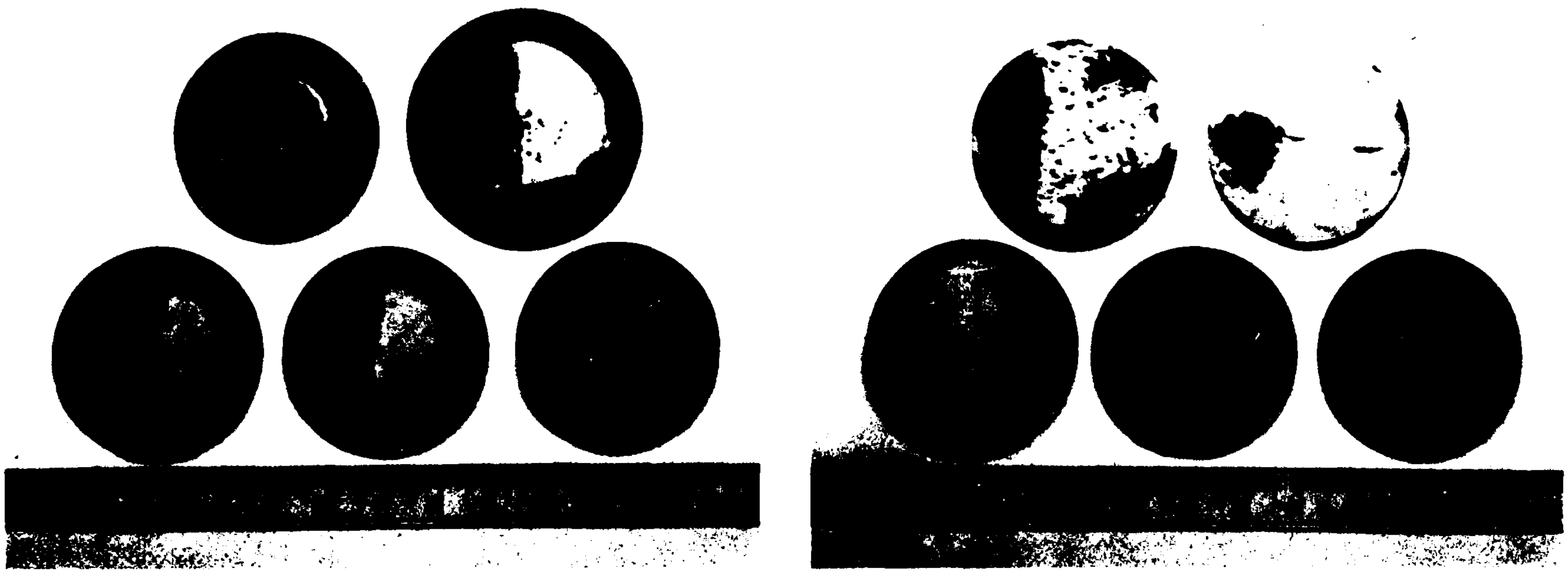
In general, mud mixtures with low water content exhibited higher viscosity, better surface adhesion, and lower evaporation rates while wet. When dried, these mixtures produced uniform gradients but rougher surfaces. Although low water content mixtures produced thicker mud layers, the mud did not adhere well to

*Coarse air-cleaned test dust was supplied by GM Phoenix Laboratories, prepared by A.C. Spark Plug Division, Flint, MI.

**Montmorillonite clay was supplied by Small Arms and Automatic Weapons Division, Aberdeen Proving Ground, MD, and was commercially available from Southern Clay Products, Incorporated, Gonzales, TX.

Table 2. Test Matrix for Mud Composition and Loading Studies

		ml H_2O in the mud mixture										
MATERIALS	LOADING PROCEDURES	1.0	2.5	5.0	10.0	20.0	25.0	30.0	35.0	40.0	50.0	100.0
2.5 g clay and 0.5 g sand	DROP						X	X	X		X	X
	DIP				X	X		X		X	X	X
3 g Arizona Road Dust	DROP	X	X	X					X			
	DIP	X	X	X					X			



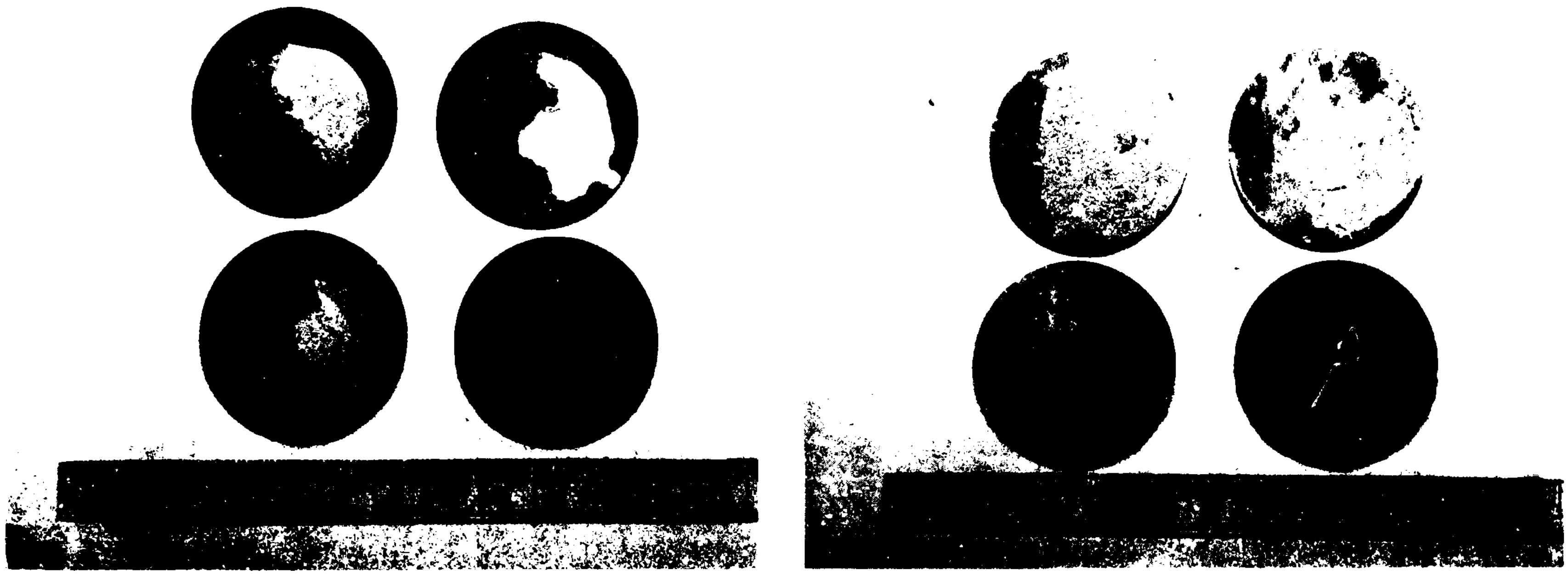
DROP

From left to right: Top: 25.0 ml H_2O, 30.0 ml H_2O
Bottom: 35.0 ml H_2O, 50.0 ml H_2O, 100.0 ml H_2O

DIP

Top: 10.0 ml H_2O, 20.0 ml H_2O
Bottom: 30.0 ml H_2O, 40.0 ml H_2O, 50.0 ml H_2O

Figure 1. Plates Showing Effect of Variation in Mud Composition (clay and sand with H_2O)



DROP

From left to right: Top: 1.0 ml H_2O, 2.5 ml H_2O
Bottom: 5.0 ml H_2O, 3.5 ml H_2O

DIP

Top: 1.0 ml H_2O, 2.5 ml H_2O
Bottom: 5.0 ml H_2O, 35.0 ml H_2O

Figure 2. Plates Showing Effect of Variation in Mud Composition (Arizona dust and H_2O)

Table 3. Results of Mud Composition and Loading Studies

Materials	ml H_2O	Loading Procedures		Observations						Total Score
				Wet Surface			Dry Surface			
		DROP	DIP	Viscosity	Surface Adhesion	Evaporation Time	Surface Adhesion	Concentration Gradient	Layer Uniformity	
2.5 g clay 0.5 g sand	25.0	X		2	3	3	5	0	3	16
	30.0	X		3	4	4	4	0	2	17
	35.0	X		3	4	4	3	0	2	16
	50.0	X		4	5	5	3	0	2	19
	100.0	X		5	5	5	3	0	2	20
	10.0		X	1	1	2	5	0	3	12
	20.0		X	2	2	2	4	0	2	12
	30.0		X	3	4	3	1	1	2	14
	40.0		X	4	5	3	1	1	1	15
	50.0		X	4	5	3	1	1	1	15
	100.0		X	5	5	5	1	1	1	18
3 g Arizona Dust	1.0	X		2	2	2	5	0	5	16
	2.5	X		2	3	3	5	0	4	17
	5.0	X		3	4	3	5	0	4	19
	35.0	X		5	4	4	4	1	3	21
	1.0		X	2	3	2	5	0	5	17
	2.5		X	2	4	2	5	0	3	16
	5.0		X	3	5	3	4	1	3	19
	35.0		X	5	5	3	4	1	3	21

Score Criteria:

	Higher	Lower
Viscosity:	1	5
Surface Adhesion:	1	5

	Faster	Slower
Evaporation Time:	1	5

	Present	Absent
Concentration Gradient:	1	0

	Smoother	Rougher
Layer Uniformity:	1	5

the plates when dried. Diluted mud mixtures provided good adhesion, thickness control, and consistent reproduction.

Table 3 shows the effectiveness of the loading procedure on increasing surface adhesion and obtaining a uniform mud thickness. For both materials, the mud added as a drop showed less film thickness uniformity and poorer surface retention than the mud applied by the dipping technique.

Based on its total lower score, the clay and sand with water mixtures loaded by the dipping method showed the best mud attachment and uniform film thickness. This method was the system selected for the subsequent evaluations. The optimal mud concentration for these characteristics occurs with a water content of 10-50 ml for the 3 g of clay and sand mixture.

Since the drying period was excessively long for these trials, other drying methods will be considered.

2.2 Mud Reproducibility Trials.

2.2.1 Purpose.

Based on the above findings, the following trials were conducted to quantitatively determine the reproducibility of forming mud layers by evaluating the weight and film thickness uniformity of the layers of mud. The trials were also to select and determine optimal soil and water concentration of the mud layers.

2.2.2 Experimental Procedure.

Mixtures of 3 g of clay and sand with 10, 20, 30, 40, or 50 ml of water were prepared for the study. These mixtures were selected because of their low total score, as discussed in the previous section.

The painted test disks were weighed before dipping in the mud mixture. Once loaded, the disks were placed on a hot plate at 80 ± 5 °C to reduce the drying time of the mud. The final disk weight was recorded after the weight had reached a constant value by repeatedly drying and cooling the sample. The weight of the mud was obtained by subtracting the weight of the clean plate from the weight of the mud-covered plate.

The mud thickness was measured using a micrometer. The plate thickness before loading and the thickness after loading and drying were recorded, and the deposited mud thickness was determined as the difference. Measurements of the thickness in different areas on the plate were used to obtain a nominal thickness range and to determine the most frequent value (mode).

Three replications of each clay and sand with water concentration were evaluated to determine the reproducibility of the samples. The test matrix is shown in Table 4.

2.2.3 Results.

Table 5 shows the results obtained together with the computation of the mean values and standard deviations.

Based on the standard deviation criteria, poor sample reproducibility was found when the soil and water mixtures approached the low water content limit. The mud solution prepared with 10 ml of water and 3 g of the clay and sand mixture had a weight standard deviation of 76.6 mg and a thickness deviation of 2.3×10^{-3} inches. These were the highest deviations obtained for any of the measurements.

The consistency of the mud layers improved by increasing the amount of water in the mixtures. A weight standard deviation of 0.2 mg and a thickness standard deviation of 0.0 inch was observed for the 30 ml of water and 3 g of clay and sand mixture; this was the most reproducible condition evaluated. Dilution to greater than 30 ml of water with 3 g of clay and sand caused reproducibility of the mud layer to decline gradually.

Based on these results, the 30 ml of water with 3 g of clay and sand was selected as the optimum mixture because it produced layers of dry mud that had the most reproducible weight and thickness. The average weight was 18.5 mg $\pm$ 0.2 mg standard deviation. The average film thickness was $\bar{2} \times 10^{-3}$ inches with no measurable deviation.

2.3 Multiple Dipping and Drying Trials.

2.3.1 Purpose.

These trials evaluated the capability to increase the weight and thickness of dried mud layers deposited on urethane-painted surfaces by using a multiple dipping procedure in conjunction with the optimum mud concentration established in the previous section. These trials also evaluated the influence of drying temperature on mud layers.

The variables that controlled the mud film characteristics were drying time, drying temperature, dip duration, and dip number.

2.3.2 Experimental Procedure.

The two mud mixtures used in this study were composed of 2.5 g of montmorillonite clay and 0.5 g of silica sand in either 30 ml of water or 20 ml of water. The mixture of 20 ml of water with 3 g of clay and sand was selected to compare results with the highly reproducible mixture of 30 ml of water with 3 g of clay and

Table 4. Test Matrix for Reproducibility Study

MATERIALS	LOADING PROCEDURE	EXPERIMENTAL PROCEDURE	EXPERIMENT NUMBER	ml H_2O in the mud mixture				
				10	20	30	40	50
2.5 g clay/ 0.5 g sand	Dipping Method	Measures & records load weight and layer thickness after drying the disks on a hot plate ($80 \pm 5^{o}C$)	1A	X				
			2A	X				
			3A	X				
			1B		X			
			2B		X			
			3B		X			
			1C			X		
			2C			X		
			3C			X		
			1D				X	
			2D				X	
			3D				X	
			1E					X
			2E					X
			3E					X

Table 5. Results of the Mud Reproducibility Study

EXPERIMENT NUMBER	LAYER WEIGHT (mg)	LAYER THICKNESS (10^{-3} in.)	LAYER THICKNESS RANGE (10^{-3} in.)	MEAN WEIGHT $\overline{MW}$ (mg)	STANDARD DEV. FROM $\overline{MW}$ (mg)	MEAN THICKNESS $\overline{M_t}$ (10^{-3} in.)	STANDARD DEV. FROM $\overline{M_t}$ (10^{-3} in.)
1A	320.3	11.0	6.5 - 21.0	298.2	76.6	8.5	2.3
2A	361.4	8.0	4.0 - 15.0				
3A	213.0	6.5	4.0 - 11.0				
1B	20.6	2.0	1.5 - 2.5	21.8	1.2	2.0	0.0
2B	21.9	2.0	1.0 - 3.0				
3B	23.0	2.0	1.5 - 3.0				
1C	2.7 *	2.0	1.0 - 2.5	18.5	0.2	2.0	0.0
2C	18.3	2.0	1.0 - 2.0				
3C	18.6	2.0	1.0 - 2.5				
1D	7.1	1.5	1.0 - 2.5	6.4	0.8	1.3	0.3
2D	5.5	1.0	1.0 - 2.5				
3D	6.7	1.5	0.5 - 1.5				
1E	-- **	--	---------	2.2	0.7	0.8	0.4
2E	2.7	0.5	0.5 - 1.0				
3E	1.7	1.0	0.5 - 1.5				

*Experimental error: due to the high temperature on the hot plate (>90 °C), the mud jumped off the surface.

**Measurement error: trial deleted.

COMMENTS: The load thickness recorded represents the value of the mode in the range of measurements taken.

Loading area: 11.4 cm^2

Micrometer Accuracy: $\pm$0.0005 inch

sand. These compositions produced the best quality and highest reproducible films in the previous test. The dipping method described in Section 2.1.2 was used for these studies. An oven was used instead of a hot plate to dry the wet, mud-covered plates to control temperature variations more accurately. The test matrix that was followed is shown in Table 6.

Table 6. Test Matrix for Multiple Dipping and Drying Studies

MATERIALS	LOADING PROCEDURE	EXPERIMENT NUMBER	NUMBER OF DIPPINGS	DRYING TEMPERATURE		
				32°C	106°C	50°C
20 ml H_2O/ 2.5 g clay/ 0.5 g sand	Dipping Method	20 A1	Maximum amount that the plate can hold without peeling off the surface	X		
		20 B1		X		
		20 C1		X		
		20 A2			X	
		20 B2			X	
		20 C2			X	
		20 A3				X
		20 B3				X
		20 C3				X
30 ml H_2O/ 2.5 g clay/ 0.5 g sand		30 A1		X		
		30 B1		X		
		30 C1		X		
		30 A2			X	
		30 B2			X	
		30 C2			X	
		30 A3				X
		30 B3				X
		30 C3				X

The multiple dipping procedure consisted of the cyclic process of dip loading the plates, drying them at a specific temperature, and measuring the layer weight and thickness after a constant weight was reached. If the mud flaked off the surface following a drying cycle, the final weight was recorded but no further evaluation of that test condition was made.

Three oven temperatures were used in this study: 32 °C, 50 °C, and 106 °C. The drying time was approximately 2.5 hr at 32 °C, 1 hr at 50 °C, and 35 min at 106 °C. Three plates were

prepared for each temperature and each mud concentration so that the mean weight, mean thickness, and the standard deviation could be determined for each condition tested.

Polyurethane-painted aluminum plates, 2.5 x 3.6 cm, were used instead of steel disks. This change was not expected to invalidate any of the previous results.

2.3.3 Results.

Table 7 lists the results of these trials, which are graphically presented in Figures 3-6.

The mixture of 20 ml of water with 3 g of mud produced the higher standard deviation values but was not able to effectively increase the layer thickness by using multiple dipping (see Figures 3 and 5). The amount of mud loaded per dip did not reach a constant level for any of the three temperatures tested. Only a single, dry layer was possible before the mud layer flaked off the surface.

The standard deviation was significantly reduced for the mixture of 30 ml of water with mud (see Figures 4 and 6). The number of dips possible before flaking occurred increased to four. At 32 °C and 50 °C, the mean weight added per layer approached a constant value (51 mg at 32 °C and 41 mg at 50 °C) after the second dip. The mean layer thickness also increased constantly by 0.001 inch per dip up to four layers maximum at 52 °C. At a drying temperature of 106 °C, the load weight and thickness per layer continued to increase with every subsequent dip; the standard deviations for the weight and thickness data also increased, reflecting a deterioration in reproducibility.

Both mud concentrations (20 ml and 30 ml of water per 3 g of solids) showed a decrease in load weight per layer when the temperature was increased from 32 °C to 50 °C. However, this trend was not observed when the temperature was increased further to 106 °C. In this case, the load weight increased to a value higher than the weight at 50 °C. This weight increase could be the result of moisture trapped in the innermost layers, while the outer layers dried faster due to the high temperature and short drying time. Attempts to increase the drying time caused the layers to crack.

These trials show that a mud mixture composed of 2.5 g of clay and 0.5 g of sand with 30 ml of water, dried in a temperature range of 32-50 °C, produces the most reliable and reproducible load weight and layer thickness when using the loading techniques described. The 50 °C drying temperature is the temperature of choice because a maximum number of layers (4) could be obtained; and the drying time, which was considerably less than the drying time at 32 °C, will accelerate the loading procedure.

Table 7. Results of Multiple Dipping and Drying Studies

TEMP.	EXP. NO.	A	B	C	D	E	F	G
DIP I								
	20A1	134.8						
32°C	20B1	80.3			110.7	27.8		
	20C1	116.9						
	20A2	76.5	1.5	0.5 - 3.0				
106°C	20B2	77.9	2.5	1.0 - 3.0	76.3	1.6	2.0	0.5
	20C2	74.6	2.0	2.0 - 3.0				
	20A3	50.0	1.5	0.5 - 2.5				
50°C	20B3	44.0	2.0	1.0 - 2.5	53.1	11.0	2.0	0.5
	20C3	65.4	2.5	1.5 - 3.0				
	30A1	*	—	———				
32°C	30B1	24.4	1.0	0.0 - 3.0	24.3	0.1	1.0	0.0
	30C1	24.2	1.0	0.0 - 2.0				
	30A2	18.2	0.5	0.0 - 1.0				
106°C	30B2	19.4	1.0	1.0 - 2.5	20.1	2.3	0.8	0.3
	30C2	22.8	1.0	0.5 - 2.0				
	30A3	17.1	1.0	1.0 - 1.5				
50°C	30B3	14.2	1.0	0.5 - 1.5	16.8	2.4	1.0	0.0
	30C3	19.1	1.0	1.0 - 1.5				
DIP II								
	20A2	120.3						
106°C	20B2	155.9			144.1	30.5		
	20C2	156.0						
	20A2	110.6						
50°C	20B3	97.1			113.8	18.5		
	20C3	133.7						
	30A1	—	—	———				
32°C	30B1	52.7	1.0	1.0 - 2.0	51.4	1.4	1.0	0.0
	30C1	50.1	1.0	0.0 - 2.0				
	30A2	48.6	1.0	0.0 - 2.0				
106°C	39B2	41.9	1.0	1.0 - 3.0	48.5	5.3	1.2	0.3
	30C2	55.0	1.5	0.0 - 3.5				
	30A3	37.6	1.0	0.5 - 2.0				
50°C	30B3	33.9	1.0	1.0 - 2.0	38.2	4.5	1.0	0.0
	30C3	43.0	1.0	0.0 - 3.0				
DIP III								
	30A1	—	—	———				
32°C	30B1	50.5	1.0	1.0 - 1.5	53.1	3.2	1.0	0.0
	30C1	55.6	1.0	1.0 - 4.0				
	30A2	60.2	2.0	1.0 - 7.0				
106°C	30B2	51.0	2.0	2.0 - 5.0	62.8	13.3	2.0	0.0
	30C2	77.3						
	30A3	42.3	1.0	0.0 - 3.0				
50°C	30B3	39.8	1.0	0.0 - 2.0	43.2	3.9	1.0	0.0
	30C3	47.4	1.0	1.0 - 2.0				
DIP IV								
	30A1	—						
32°C	30B1	58.3			51.9	7.8		
	30C1	45.5						
	30A2	94.0						
106°C	30B2	66.2			84.6	15.9		
	30C2	93.6						
	30A3	*	—	———				
50°C	30B3	36.7	1.0	0.0 - 1.0	43.2	8.0	1.0	0.0
	30C3	49.6	1.0	0.5 - 1.0				

A = Layer Weight (mg per layer)

B = Layer Thickness (10^{-3} in. per layer)

C = Layer Thickness Range (10^{-3} in. per layer)

D = Mean Weight (mg)

E = Standard Deviation from Mean Weight (mg)

F = Mean Thickness (10^{-3} in.)

G = Standard Deviation from Mean Thickness (10^{-3} in.)

* Experimental Error While Loading

COMMENTS:

The layer thickness recorded represents the value of the mode in the range of measurements taken.

The value of the load weight and thickness is expressed per layer (without counting the previous layers)

Loading area: 9 cm^2

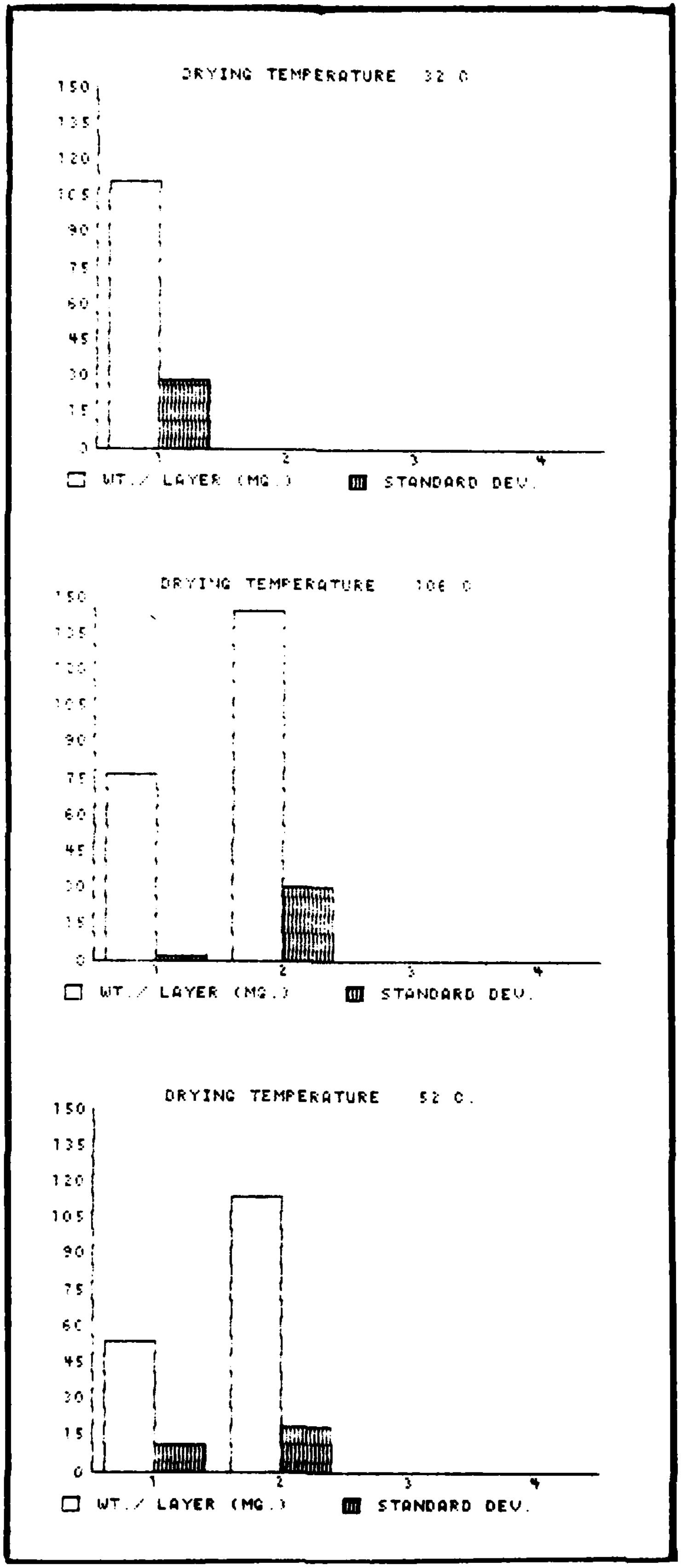


Figure 3. Effect of Number of Dips and Drying Temperature on Mud Weight (20 ml H_2O with 3 g clay and sand)

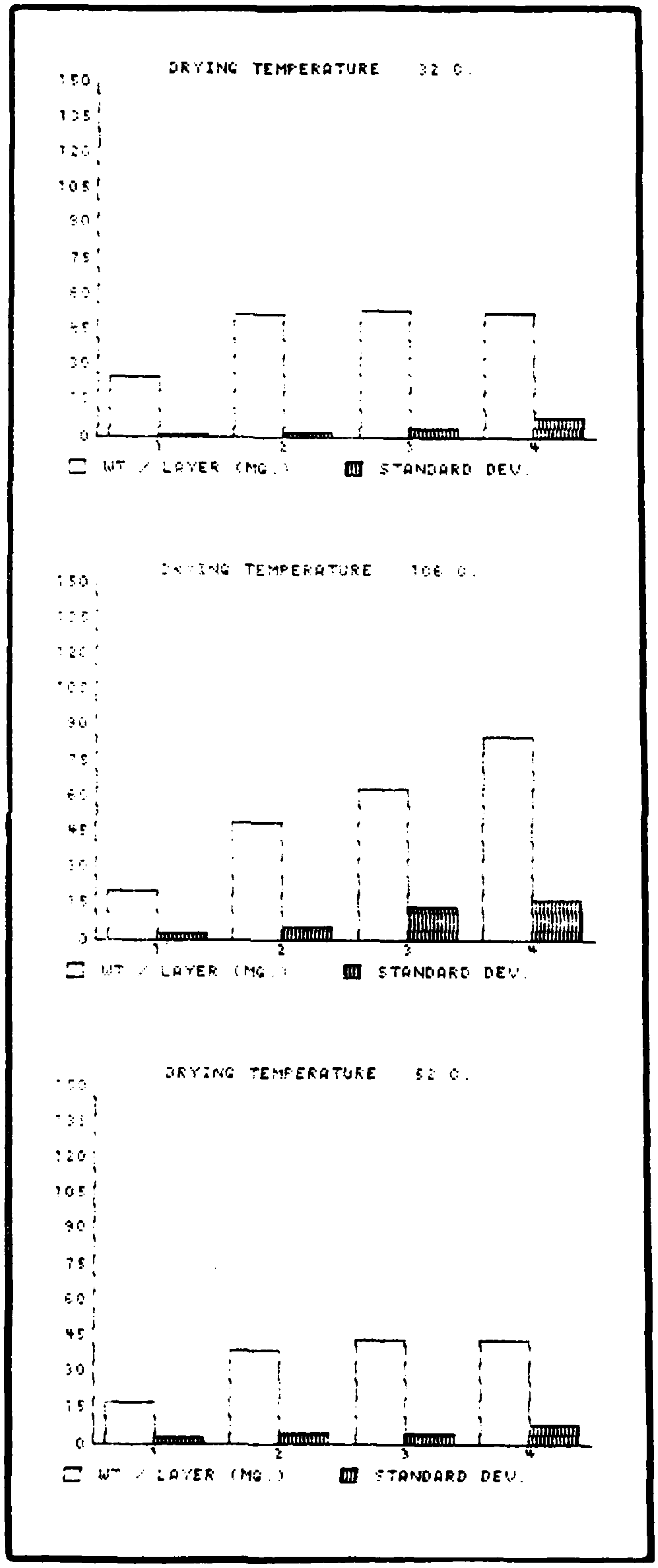


Figure 4. Effect of Number of Dips and Drying Temperature on Mud Weight (30 ml H_2O with 3 g clay and sand)

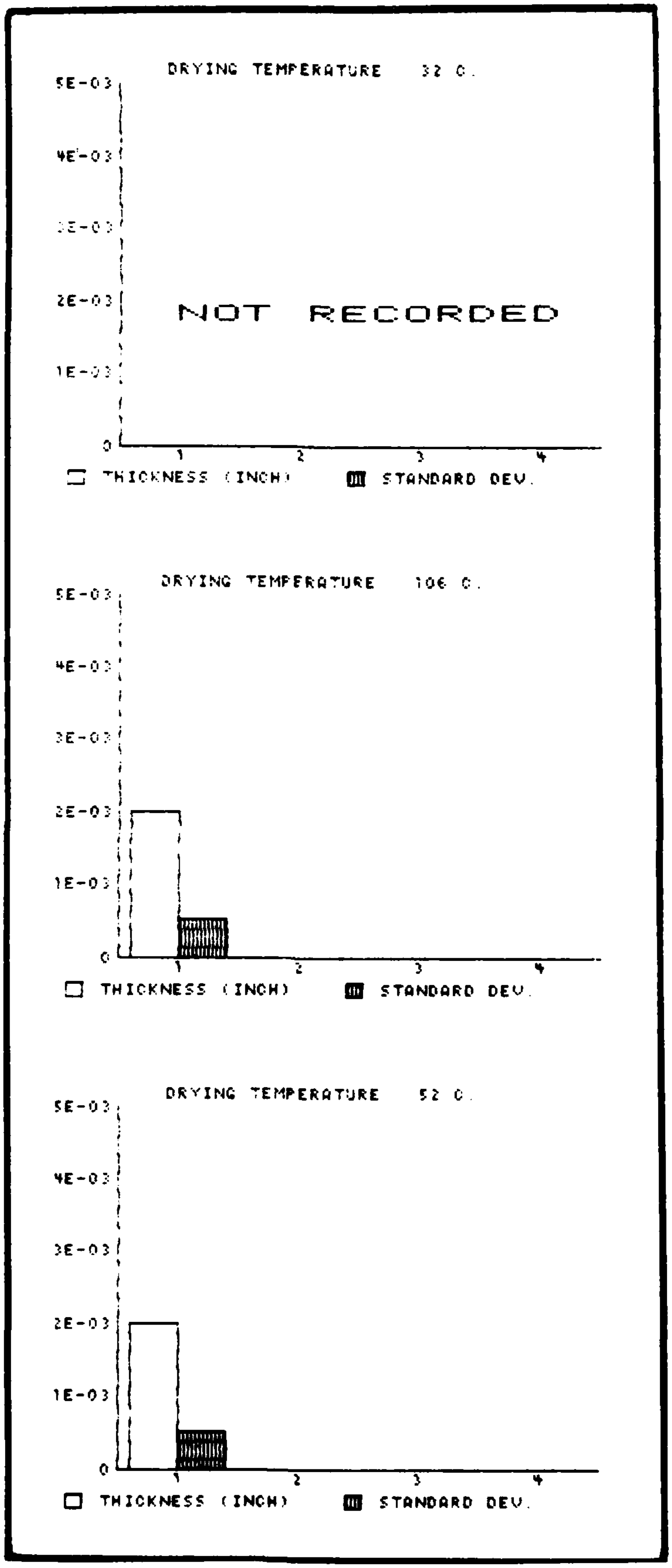


Figure 5. Effect of Number of Dips and Drying Temperature on Mud Thickness (20 ml H_2O with 3 g clay and sand)

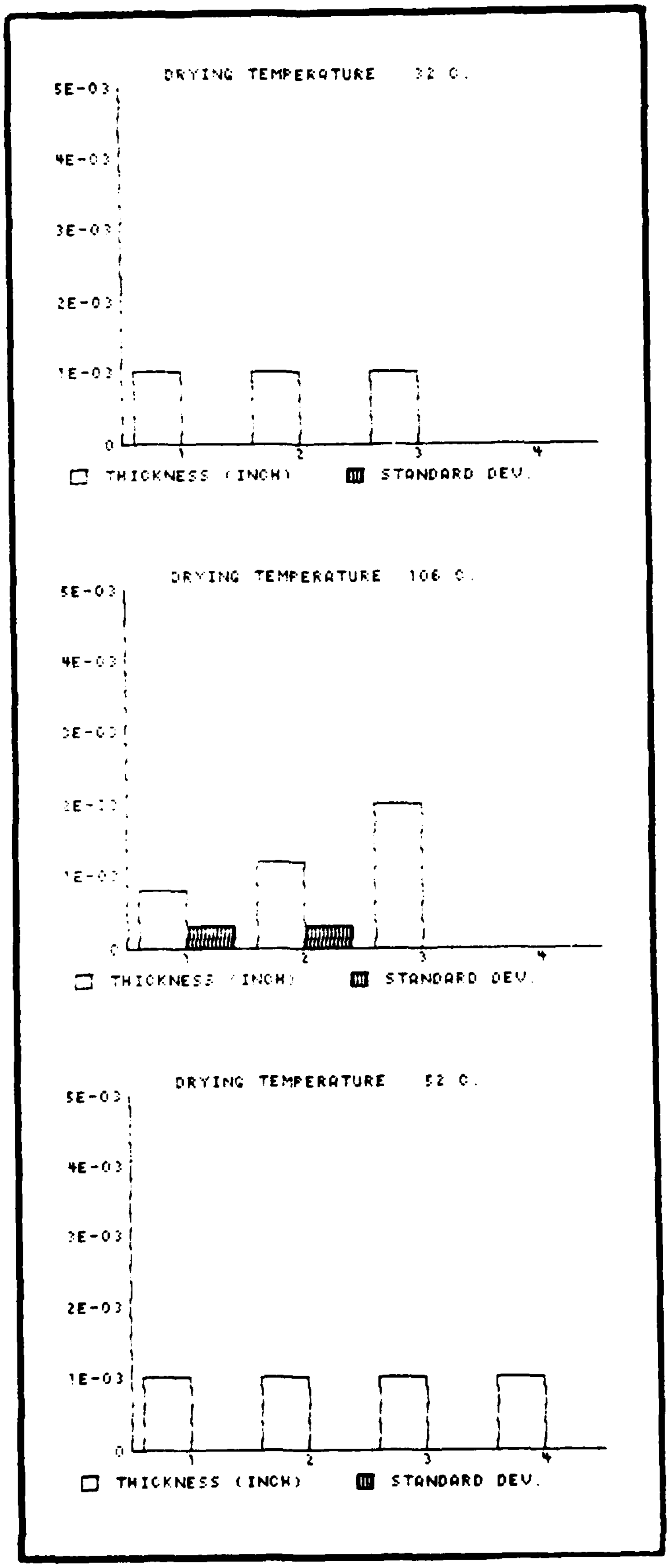


Figure 6. Effect of Number of Dips and Drying Temperature on Mud Thickness (30 ml H_2O with 3 g clay and sand)

3. DISCUSSION

The materials, conditions, and procedures that were evaluated provide an understanding of the parameters that control the loading of mud on polyurethane-painted surfaces. Clay and sand with water mixtures provide better adhesion, layer thickness uniformity, and application reproducibility than Arizona road dust and water mixtures. However, these measures of performance degrade as the water content of the mixtures is lowered or raised from an optimum value. The trials also demonstrate that placing the mud mixtures on the sample plates is not as satisfactory as dipping the plates in the mixture. By using the dipping process, it is possible to produce uniformly coated plates, and the layer thickness can be controlled by a multiple dipping and drying cycle. While forced drying in an oven is more effective and efficient than using either ambient air or a hot plate, the temperature is critical. The mixture of 30 ml of water with 3 g of montmorillonite clay and silica sand produced uniformly coated, mud layers (up to four layers thick without flaking from the test plate) when dried at either 32 °C or 50 °C. However, when dried at 106 °C there was a loss in uniformity of thickness and weight between layers. Consequently, a drying temperature of 50 °C is recommended for producing the most reproducible coating and reasonable drying time: 1 hr per layer for the plates used in these trials.

The procedure developed for reproducibly coating sample plates with a standard mud mixture based on this study follows.

a. Clean sample plates to remove any oil film or dirt.

b. Prepare mud mixture in the following proportions: montmorillonite clay - 2.5 g, silica sand - 0.5 g, and distilled water - 30 ml. This is equivalent to a mixture of 5 parts clay, 1 part sand, and 60 parts water.

c. Blend mixture thoroughly with stirrer for approximately 30 min, and let the mixture settle for 30 min more.

d. Dip test surface of plate into mixture and hold for 10 sec.

e. Withdraw plate and slowly rotate edge down for 10 sec to drain off excess mixture.

f. Place plates in convection oven to dry at 50 °C for 1 hr.

g. Remove plates and cool. This procedure will provide a mud layer weight of 16.8 ± 2.4 mg and a layer thickness of $1 \times 10^{-3} \pm 0.0$ inches on one surface of a 9-cm^2 (1.4 square inches) test plate.

h. If a thicker mud layer is required, repeat steps d through g. Up to three additional layers can be applied, resulting in further weight increases for each loading cycle of 38.2 $\pm$ 4.5 mg, 43.2 $\pm$ 3.9 mg, and 43.2 $\pm$ 8 mg and further layer thickness of 1 x 10^{-3} $\mp$ 0.0 inches per cycle.

4. CONCLUSIONS

- A procedure was developed for preparing reproducible mud coatings on test plates for use in controlled decontamination studies.

- Montmorillonite clay, silica sand, and water in the proportion of 5:1:60 parts (2.5:0.5:30 g) produced a standard mud that exhibited good surface adhesion and mud layer uniformity when applied to polyurethane-painted test plates.

- Application of the mud mixture by multiple dipping and oven drying at 50 °C is an effective technique for controlling layer thickness.

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